

An environmental gradient change of *Picea mongolica* seedling from the center of a forest canopy gap in forest-steppe ecotone in Inner Mongolia Autonomous Region of China

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Abstract: In sandy forest with a forest canopy gap for a period of over 30 years, the spruce (*Picea mongolica*) seedlings were monitored on two 5-m-wide transects from the center of a large gap into the surrounding forest. The farther they were to the far center, the taller grew the seedling and the more is the number of seedling. There were many seedlings under the canopy but almost all seedlings died before they grow up. Along the forest edge, growth of seedlings was temporarily enhanced by lateral penetration of light from the gap. The implications for natural forest regeneration dynamics are discussed. Our results prove that in *P. mongolica* forest a gap disturbance creates a non-uniform environment for regeneration of the species, and determines that the forest was a non-even aged forest.

Keywords: *Picea mongolica*; Sandy forest; Seedling growth; Canopy gap; Photosynthetically active radiation; Soil moisture

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Introduction

Picea mongolica W. D. Xu is an endemic and endangered species in Inner Mongolia Autonomous Region of China (Xu *et al.* 1994). As to ecosystem, the spruce forest locates at the ecotone between forest zone and steppe zone (Fig. 1). As to cultivate way, the forest is in the ecotone between agricultural district and pastoral area. The area is also a transitional zone from Daxing'an Mountains to Hunshandake Sandy Land (Xu *et al.* 1998).



Fig. 1 Location of the study area (2 hm²)

Disturbances that create gaps of various sizes are a common feature of the ecology of boreal coniferous forests (Bergeron *et al.* 1998; Olli *et al.* 2003). In natural forests, minor perturbations such as insect damage and timber harvesting creating small gaps

are more common in sandy forest in the north of China (Zou *et al.* 1998). The mean area of a gap is 0.1 hm² in *P. mongolica* forest, and the guidelines for preservation of valuable habitats increase the length of the edge considerably (Xu *et al.* 1998). Gap disturbance opens space and releases resources that initiate vegetation succession and facilitate tree regeneration (Bazzaz *et al.* 1994; DeChantal *et al.* 2003; Kuuluvainen 1994; Lertzman 1992; McGuire *et al.* 2001; Li *et al.* 1997). Many researches on various types of forests have focused on the effect of gaps on plant species composition (Collins *et al.* 1988) on availability of resources, particularly light (Messier *et al.* 1995; Rockway *et al.* 1998) and on microclimate (Chen *et al.* 1993, 1995; Tan *et al.* 2000). In smaller gaps, most of the gap areas are likely influenced in some way or another by the surrounding forest.

Gap-associated dynamics of the tree seedling is considered as a major factor in determining the structure of forest canopy (Platt and Strong, 1989). The importance of gaps in seedling recruitment increases in old-growth forests, where variation in types of disturbance events leads to diversity of 'regeneration niches' (Grubb, 1977; Drobyshev, 1999). The most prevalent paradigm of forest regeneration dynamics is gap centered, both temporal and spatial: seedlings are released from shade suppression by gap creation and it is competition between them thereafter, in the gap environment, which determines the future forest composition (Brown *et al.* 1992). It is frequently proposed that the size of a forest canopy gap exerts the most important control over the relative competitive status of seedlings. The size of a canopy gap is the main determinant of both the amount and the duration of isolation, which penetrates the forest. It is known that spruce seedlings in sandy forest differ in their growth response at different levels of photosynthetically active radiation (PAR). Gaps may also alter the spatial patterning of fine roots, soil nutrients and soil moisture (Jones *et al.* 2003; Wilczynski *et al.* 1993; Liu *et al.* 2002). In sandy forest, soil moisture is a key for seedling growth and survival; therefore the soil moisture would affect the number and height of spruce seedling in the gap (Zou *et al.*

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2001). Denslow (1980) has argued that a species may regenerate preferentially beneath a certain size of canopy gap, which creates optimum conditions for its growth since species specializations bestow competitive superiority in one particular gap size but involve adaptive compromises that restrict success in gaps of differing size. Despite considerable research effort there has been remarkably little experimental evidence to test this hypothesis of niche differentiation along a gap size continuum amongst sympatric tree seedlings.

Gaps alter the structure of a forest and have been shown to have non-uniform soil and light environments (Brandani *et al.*, 1988; Brown 1993; Liang *et al.* 2001). The gap-phase regeneration hypothesis needs to incorporate the implications of within-gap heterogeneity for competition between species (Brown 1996). This paper reports the results of measurements about 30-years-old wild seedlings of *P. mongolica* growing along the transect from the center of a gap into the surrounding sandy forest in Baiyinaobao Natural Reserve of Inner Mongolia Autonomous Region, China. The objective of the study was to determine whether *P. mongolica* would show changes in its relative competitive status along the light and soil moisture gradient from the gap center to surrounding.

Materials and methods

Study site

The study was conducted in Baiyinaobao Natural Reserve (43°30'–43°36' N, 117°06'–117°16' E, and 1420 m in altitude) in the east of Inner Mongolia Autonomous Region, China. The climate is a typical temperate continent steppe type. The mean annual temperature is -1.4 °C. The annual accumulated temperature of >5 °C is 1942 °C (Xu 1985). The mean annual precipitation is 448.9 mm and the potential annual evaporation is 1 526 mm. It is a typical semi-arid region in the north of China. The length of the frost-free season is 65 days.

Spruce-dominated forests grow on most of the territory of the reserve. While stands with little portions of broad-leaved species (mainly with *Betula platyphylla* Suk., and *Populus davidiana* Dode.) occupy lower parts of well-drained slopes. The mean age of the stand was 110 years and it had originated by natural regeneration. The mean height of trees was 17 m. The stand had 950 stems·hm⁻², and stem volume was 450 m³·hm⁻². The zonal soils of the area are mainly black soil and brown soil on dunes, which are podzolic, and there also are meadow soil, marsh soil and salt soil on riverbanks, and meadows. The groundwater table is at a depth of 5–8 m. The mean thickness of the humus layer was ca. 50 mm. The shrub layer mainly consisted of *Ostryopsis davidiana* Decne. *Cotoneaster melanocarpus* Lodd. *Dasiphora fruticosa* (L.) Rydb. *Rosa davurica* Pall. The herb layer consisted mainly of *Aneurolepidium chinense* (Trin.) Kitag., *Agropyron cristatum* Gaertner., *Calamagrostis epigeios* (L.) Roth., and *Artemisia frigida* Willd. The ground layer was dominated by *Phytidium rugosum* (Hedw.) Kindbs., and *Phytidiadphs trguetrus* (Hedw.) Warnst.

Experimental area

In the middle of a mature *P. mongolica* stand, an experimental area of 80 m × 80 m was set up. All the trees were mapped in the experimental area and in its close vicinity by using a tachymeter. In the middle of the area, there is a canopy gap, an approximately isodiametric area of 1000 m² with a diameter of about 36 m (Fig.

2). The gap is about 30 years old according to our investigation, and there are a lot of spruce seedlings of various ages.

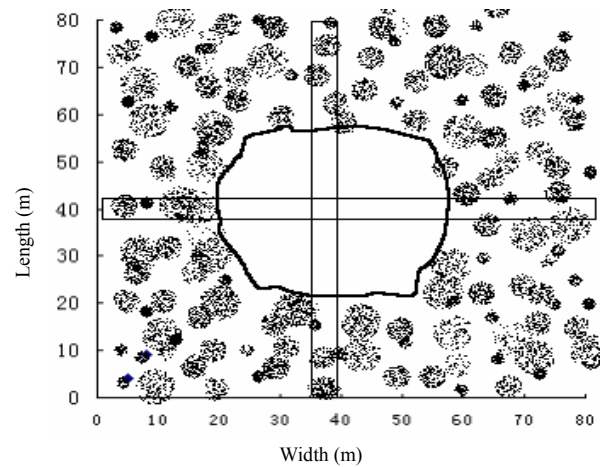


Fig. 2 The map of the tree crowns in the experimental area showing the location of the gap edge

(The circle denotes the gap, and darker dots show the remaining living trees. The size of the dot is directly related to the width of the tree crown)

Study methods

Two 5-m-wide transects were laid out in north-south and west-east directions 40 m from the center of a gap of approximately 45% canopy openness, into the surrounding closed forest. The experimental gap was located in Baiyinaobao Natural Reserve and had a comparable microclimate. PAR was measured continually with an integrating quantum sensor, at a height of 0.5 m, for a period of 2 months in the gap center and every 5 m along the transect. Soil moisture was measured continually for a period of 2 months in the gap center and every 5 m along the transects.

P. mongolica forest in Baiyinaobao Natural Reserve is characterized as a pure forest. *P. mongolica* is shade-tolerant climax sandy forest tree and highly specialized adaptation to gap micro-environment. The growth and survival of the spruce seedlings found growing along these transects were monitored in 2000 after gap creation for over 30 years. Both PAR and soil moisture are compared with those made in two nearby closed forest control plots of 120 m² and 240 m² located at least 100 m from any canopy gap.

Statistical analysis

The effects of sampling year and position in the gap and under the canopy were estimated by means of ANOVA. The statistical data was analyzed by using Microsoft Excel 2000.

Results

In *P. mongolica* forest, gap alters the light environments of various plant species. In Fig. 3, a vertical projection of the edge of the canopy gap would fall at approximately 15 m from the gap center along transects. PAR is non-uniform within the gap. In this gap mean daily PAR receipts at the gap edge were approximately half of that at the center. There is a penumbral zone around the gap, which also receives more PAR than the closed forest. Mean daily PAR receipts at the points of up to 15 m from

the gap edge are significantly higher than mean PAR receipts measured simultaneously at four points in closed forest control plots ($p < 0.05$, Student's t -test for independent samples with unequal variance).

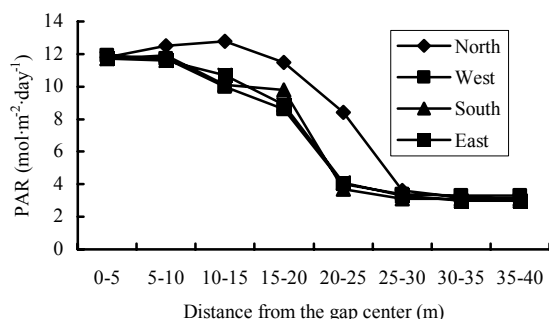


Fig. 3 Mean daily PAR receipts in different directions of 5-m-wide transects from the center of a large forest canopy gap into the surrounding forest

In the gap, soil moisture changes along transects due to the shift of PAR. In Fig. 4, the curve shows the mean soil moisture along transects from gap center into the surrounding forest. A horizontal change of soil moisture is that soil moisture increases due to the reduce of PAR receipts up to the gap edge from outward to the gap center, and then decreases to a low level due to the absorption by root system of *P. mongolica* under the closed forest. Soil moisture is non-uniform within the gap. In this gap, mean soil moisture up to 15 m from the gap center were significantly higher than those measured simultaneously at four points in closed forest control plots, and mean soil moisture in south direction were significantly higher than those in north direction ($p < 0.05$, Student's t -test for independent samples with unequal variance).

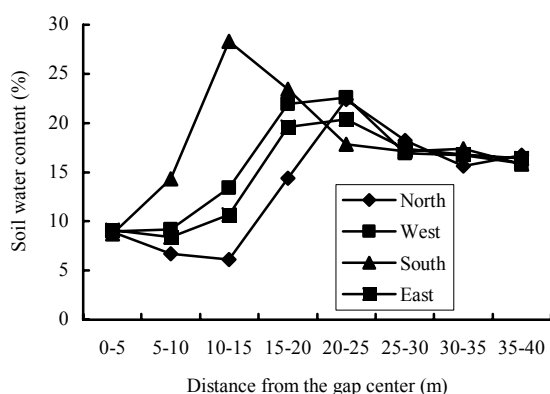


Fig. 4 Mean soil moisture in different directions of 5-m-wide transects from the center of a large forest canopy gap into the surrounding forest

P. mongolica is shade-tolerant species. There are many seedlings (mean about 12 /5m²) under the canopy, and there is little variance. However, they have difficulty to grow up because of low PAR level. A lot of seedlings come into being, and a lot of die out. Once the seedlings have appropriate environment, they will grow rapidly. In Fig. 5 the seedling density in each direction of transects is compared with the mean density of seedlings

growing in closed forest control plots. The closer they are to the gap center, the less they are. But on the edge of gap, there are more and more seedlings. Significant differences ($p < 0.05$, Student's t -test for independent samples with unequal variance) are W (10–15m and 15–20 m) and S (10–15m and 15–20m). Only those seedlings, which were growing on the gap edge were significantly denser than those found in the center of gap and under closed forest.

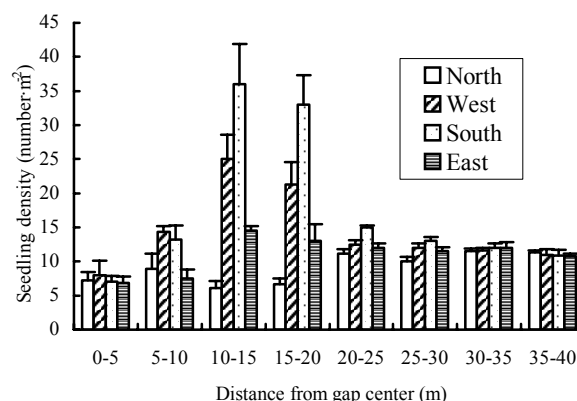


Fig. 5 Mean seedling density in different directions of 5 m wide transects from the center of a large forest canopy gap into the surrounding forest

Error bars represent the 95% confidence interval around mean values

Seedling growth of *P. mongolica*, including height growth is influenced by many environmental factors, such as light, temperature, soil moisture, etc. Fig. 6 shows mean changes in seedling height over time in three sections of transects, the gap, the gap edge and closed forest. Seedlings in the gap have grown and continue to grow at a very low rate because of low soil moisture, strong light, and high temperature (the maximum is 45.7°C in July). Seedlings in closed forest do so due to low PAR receipts. Seedlings on the edge of the gap showed significant increase in height for appropriate light and soil moisture. Significant differences ($p < 0.05$, Student's t -test for independent samples with unequal variance) are in the west (10–15 m and 15–20 m) and the south (10–15 m and 15–20 m). Only those seedlings which were growing in the gap edge were significantly taller than those found in closed forest and in the center of the gap.

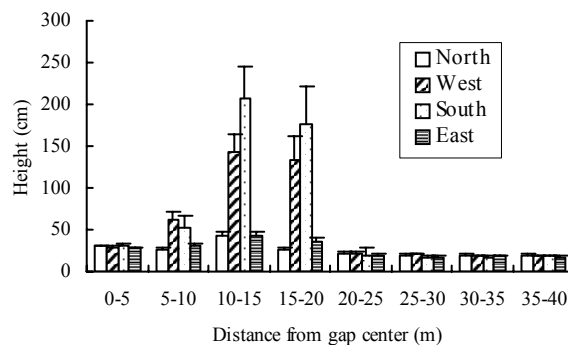


Fig. 6 Mean seedling height in different directions of 5-m-wide transects from the center of a large forest canopy gap into the surrounding forest

Error bars represent the 95% confidence interval around mean values

Discussion

In a forest, canopy gaps are a non-uniform environment for the growth of seedlings. PAR receipts decline away from the gap center and may penetrate many meters into the surrounding forest (Fig. 3), which results in the change gradient of soil moisture in the gap (Fig. 4). It has been hypothesized that such a gradient may create opportunities for partitioning of the gap between species adapted for optimum growth at different levels of PAR and soil moisture. The environment and climate of the study site are typical temperate continent steppe type. It is semi-arid area. The environment is non-uniform in each micro-climate of canopy gap. There are gradients in PAR level and soil moisture from the center of the forest gap. Spruce-dominated forests grow on most of the territory of the reserve. And the structure of the vegetation is very simple. Therefore, the ecotone is nearly uniform in different years and different seasons. When we took the veracity and accuracy of experiment into consideration, were confronted with the problem of whether we would choose several gaps or only one gap but could provide us with more data. As to the area of the experiment, we chose a typical study site which accounts for an area of 80 m × 80 m. In the middle of the area, there is a canopy gap an approximately isodiametric area of 1000 m² with a diameter of 36 m. And in the larger study of gap-phase regeneration dynamics two 5-m-wide transects were laid out in north-south and west-east. We can say our methods and data can best account for the aim of our experiment. Popma *et al.* (1988) found differences in structure and floristic composition between pioneer assemblages in gap center and gap border areas. In our research, *P. mongolica* seedlings do change density rank along the PAR and soil moisture gradient from gap center to closed forest, whilst there is clear partitioning of the gap in terms of height growth. Timan (1994) has shown that well dispersed species may succeed in colonizing sites not occupied by superior competitors. Dispersal may occur temporal as well as spatial. Seedlings which persist for long periods in shade will increase their chances of encountering a gap at a time when less persistent species are no longer present. Persistence may be as effective a strategy as rapid growth for competing for space.

A lot of seedlings have persisted on the gap edge and have become significantly taller than those under closed forest and in the center of the gap. In a gap of this size a forest edge zone 5 m in width may have an area approximately equivalent to that of the gap itself. Consequently, a gap may provide as many sites for the regeneration of shade tolerant seedling species around its periphery as it does for light demanding species within the gap area. This would appear to contradict the hypothesis that frequency of occurrence of gaps of a particular size will affect the probability of regeneration of species adapted for optimum growth under the microclimatic conditions of that gap. Intra-gap partitioning implies that a wide range of species may be successful in any size of gap. Large gaps may, in practice, create a greater opportunity, around their periphery, for the regeneration of species which have a competitive advantage in partial shade, than small gaps do.

P. mongolica is an endemic tree species in China, and an important afforestation species in Three-North area (Northwest China, North China, and Northeast China) in semi-humid and semi-arid area (Xu *et al.* 1998; Xu *et al.* 1992; Xu 1993). The spruce is a slow-growth species in early 20 years (Xu *et al.* 1993). The seedlings still receive overhead illumination they now shade

those seedlings beneath them and prevent lateral penetration of PAR beneath the canopy. The implication of this is that intra-gap partitioning may be a transient effect. Whilst more shade tolerant species may preferentially persist and grow around the gap periphery their growth is quickly suppressed by the more rapid growth of gap center species. Individuals of persistent species may benefit from sidelight from a number of gaps forming in their vicinity. An important issue for future research is whether some species are able to attain full size by periodic growth interspersed with long periods of shade suppression. Some foresters maintain that only those trees, which maintain rapid growth from early in life, are likely to reach reproductive maturity. It is known that *P. mongolica* may show increased growth rates in response to canopy opening.

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